CURVILINEAR VALVE PIN CONTROLLER FOR INJECTION MOLDING

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of and claims the benefit of priority under 35 USC § 120 to U.S. patent application serial nos. 09/400,533 filed September 21, 1999 and PCT/US00/25861 filed September 21, 2000 and 09/503,832 filed February 15, 2000 and PCT/US01/04674 filed February 13, 2001 and 09/656,846 filed September 7, 2000.

This application also claims the benefit of priority under 35 U.S.C. §§119 and 120 to U.S. Provisional Application Serial No. 60/250,723 filed December 1, 2000 and US Provisional Application Serial no. 60/257,274 filed December 21, 2000 and U.S. Provisional Application Serial No. 60/277,023 filed March 19, 2001.

The disclosures of all of the foregoing applications and U.S. Patent Nos. 5,916,605 and 5,871,786 and 5,894,025 and 5,885,628 and 6,062,840 and 5,948,448 and 5,948,450 and 6,294,122 and 6,261,084 and 5,980,237 and 5,492,467 and 5,674,439 and 5,545,028 and 4,204,906 and 4,389,002 and 5,554,395 and 6,309,208 and 6,287,107 and 6,254,377 and 6,261,075 and U.S. Patent Application Serial Nos. 09/063,762 and 09/478,174 and 09/699,856 and 09/618,666 and 09/716,725 and 09/841,322 and U.S. Provisional Application Serial No. 60/299,697 are all incorporated herein by reference in their entirety.

Background of the Invention

The present invention relates to apparati and methods for controlling flow rates in injection molding and more particularly to curvilinear bulbous protrusions on a valve pin for controlling the flow rate of fluid polymeric materials according to a selectively variable rate of flow.

The present invention also relates to automatic control of plastic flow through injection nozzles in a molding machine including proportional control of plastic flow via proportional control of the actuator mechanism for a valve for a nozzle particularly where two or more nozzles are mounted on a hotrunner for injection into one or more mold cavities. The proportional control is achieved via the use of one or more sensors which senses a selected condition of the plastic flow through a manifold, nozzle or into a mold and the use of the recorded condition in conjunction with a selected nozzle design, hotrunner/manifold design, actuator design, actuator drive mechanism and/or flow control mechanism. Proportional control of melt flow typically refers to control of the rate of melt flow according to an algorithm utilizing a value defined by a sensed condition as a variable.

Summary of the Invention

The present invention provides a fluid material flow control apparatus which comprises a valve pin slidably disposed within a flow channel having an exit aperture through which fluid material is injected into a mold cavity. The valve pin comprises an elongate pin which is controllably driven by a controllably drivable actuator in a reciprocal back and forth motion through the flow channel leading to the exit aperture. The valve pin has a bulbous protrusion or bulb or enlarged diameter portion along its length wherein the bulbous protrusion has a continuously smooth curvilinear exterior surface extending from an upstream end to a downstream end of the bulbous protrusion. The bulbous protrusion has an intermediate cross-sectional circumferential surface having a maximum diameter at a selected position along the axial length of the protrusion for mating with an interior surface of the channel having a

complementary diameter to the maximum diameter of the bulbous protrusion. The mating of the bulb and complementary surface of the channel acts to stop fluid flow through the channel.

The complementary interior surface of the channel with which the maximum diameter exterior circumferential surface of the bulbous protrusion mates is typically arranged/disposed within the channel as a straight restricted throat section of the channel e.g. cylindrical in shape/geometry. The valve pin and the bulbous protrusion have a common axis. An upstream section of the valve pin is mounted within a complementary aperture in a housing, hotrunner or manifold for slidable reciprocal back and forth movement along the axis of the pin. The pin is mounted such that the bulbous protrusion portion of the pin is reciprocally movable back and forth through a selected length of the restricted throat section of the channel. The intermediate maximum diameter circumferential surface of the bulbous protrusion which mates with the restricted throat section of the channel is complementary in geometry to the throat section, typically comprising, for example, a short straight surface on the exterior of the bulb (e.g. in the shape of a cylinder) which matably slides along the complementary short straight surface of the throat as the bulb is moved axially through the throat. When the maximum diameter circumferential surface of the bulb is moved out of mating contact with the interior surface of the throat, polymer fluid which is being fed under pressure through the channel is able to pass through the throat section along a path toward the exit of the channel where the polymer fluid first passes smoothly along the upstream continuously curvilinear surface of the bulb and subsequently along the downstream continuously curvilinear surface of the bulb.

The pin has a length selected such that the pin can be controllably driven through at least a first position where polymer fluid flow is stopped when the maximum diameter circumferential surface of the bulbous protrusion mates with the complementary throat surface, a second

downstream position where polymeric fluid flow is enabled between the exterior curvilinear surface of the bulbous protrusion and the interior surface of the channel leading to the exit aperture of the nozzle and a third position where a terminal downstream end of the valve pin mates with a complementary exit aperture surface to open and close the aperture.

The pin may alternatively have a selected length such that the terminal downstream end of the pin does not engage or mate with any surface at or near the exit aperture of the nozzle during the course of its driven stroke and thus does not open and close the exit aperture of the nozzle at any time.

The pin is controllably movable/slidable via the actuator to any desired intermediate flow position. In the intermediate flow positions the rate of polymeric fluid flow is varied depending on the axial distance between the maximum diameter circumferential surface of the bulbous protrusion and the complementary mating throat surface, the fluid flow rate being greater, the greater the axial distance.

Most typically the actuator is driven according to a programmably controllable algorithm which receives variable inputs based on signals received from one or more sensors which monitor one or more properties or conditions of the fluid polymeric material which is being injected through the manifold/hotrunner and/or into the mold cavity. Sensing one or more fluid properties such as pressure, temperature and fluid flow rate may be used to monitor the fluid and signals from such sensors input to the algorithm which control the drive of the actuator which in turn controls the position of the valve pin.

The curvilinear surfaces of the bulbous protrusion of the pin regulate a smooth transition of polymer fluid flow rate from upstream to downstream along the exterior curvilinear surface of

the bulb as the bulb of the pin is moved axially through the channel either further away from or closer toward the restricted throat section.

In accordance with the invention therefore there is provided an apparatus for controlling the rate of flow of fluid material through a flow channel having an exit aperture leading to a mold cavity, the apparatus comprising: a pin having an axis slidably mounted in a housing containing the channel for back and forth axial movement of the pin through the channel; the pin having a bulbous protrusion along its axis, the bulbous protrusion having a smooth curvilinear surface extending between an upstream end and downstream end of the bulbous protrusion and a maximum diameter circumferential surface intermediate the upstream and downstream ends of the bulbous protrusion; the channel having an interior surface area portion which is complementary to the maximum diameter circumferential surface of the bulbous protrusion of the pin; the pin being slidable to a position within the channel such that the maximum diameter circumferential surface of the bulbous protrusion mates with the complementary interior surface portion of the channel.

The valve is drivable through at least a first position wherein polymer fluid flow is stopped when the maximum diameter circumferential surface of the bulbous protrusion mates with the complementary interior channel surface and a second downstream or upstream position where polymer fluid flow is enabled between the curvilinear surface of the bulbous protrusion and an interior surface of the channel. The valve is preferably drivable through a third downstream position where a terminal downstream end of the valve pin mates with a complementary exit aperture surface to stop fluid flow.

The maximum diameter circumferential surface of the bulbous protrusion is preferably cylindrical in shape and the complementary interior surface portion of the channel is preferably cylindrical in shape.

The pin is slidably mounted in the housing in an aperture which may have a diameter equal to or greater than the diameter of the maximum diameter circumferential surface of the bulbous protrusion of the pin.

Further in accordance with the invention there is provided, in an injection molding machine having at least one nozzle for delivering melt material from a manifold to a mold cavity, apparatus for controlling delivery of the melt material from the nozzle to the mold cavity, the nozzle having an exit aperture communicating with a gate of the cavity of the mold and being associated with an actuator interconnected to a melt flow controller, the apparatus comprising: a sensor for sensing a selected condition of the melt material through the nozzle; an actuator controller interconnected to the actuator, the actuator controller comprising a computer interconnected to a sensor for receiving a signal representative of the selected condition sensed by the sensor, the computer including an algorithm utilizing a value corresponding to a signal received from the sensor as a variable for controlling operation of the actuator; wherein the actuator is interconnected to and controls movement of a pin having a bulbous protrusion, the pin and the bulbous protrusion having a common axis, the pin being slidably mounted in a channel leading to the gate for back and forth movement axial movement of the bulbous protrusion through the channel; wherein the bulbous protrusion has a maximum cross-sectional diameter section having an exterior surface which is matable with a complementary interior wall surface section of the channel at a selected position along the back and forth axial movement of the bulbous protrusion through the channel.

The at least one nozzle preferably has a seal surface on a tip end of the nozzle, the nozzle being expandable upon heating to a predetermined operating temperature, the nozzle being mounted relative to a complementary surface surrounding the gate such that the seal surface disposed on the tip end of the nozzle is moved into compressed contact with the complementary surface surrounding the gate upon heating of the nozzle to the predetermined operating temperature. The tip end of the nozzle may comprise an outer unitary piece formed of a first material and an inner unitary piece formed of a second material, the first material being substantially less heat conductive than the second material.

The sensor typically comprises a pressure transducer interconnected to at least one of the bore of a nozzle or a mold cavity for detecting the pressure of the melt material. The actuator controller typically further comprises a solenoid having a piston controllably movable between selected positions for selectively delivering a pressurized actuator drive fluid to one or the other of at least two chambers of the actuator.

The exterior surface of the maximum diameter section of the bulbous protrusion may form a gap between the exterior surface of the bulbous protrusion and the complementary surface of the channel upon axial movement of the pin to a position where the exterior surface of the bulbous protrusion and the complementary surface of the channel are not mated, wherein the size of the gap is increased when the valve pin is retracted away from the gate and decreased when the valve pin is displaced toward the gate. Alternatively, the exterior surface of the maximum diameter section of the bulbous protrusion forms a gap between the exterior surface of the bulbous protrusion and the complementary surface of the channel upon axial movement of the pin to a position where the exterior surface of the bulbous protrusion and the complementary

surface of the channel are not mated, wherein the size of the gap is decreased when the valve pin is retracted away from the gate and increased when the valve pin is displaced toward the gate.

At least one of the valves may have a bore and a valve pin, the apparatus further comprising a plug mounted in a recess of the manifold opposite a side of the manifold where the at least one nozzle is coupled, the plug having a bore through which a stem of the valve pin of the nozzle passes, the valve pin having a head, the bore of the plug through which the stem passes having a smaller diameter than the valve pin head at the valve pin head's largest point and the recess of the manifold having a larger diameter than the diameter of the valve pin head at the valve pin head's largest point, so that the valve pin can be removed from the manifold from a side of the manifold in which the recess is formed when the plug is removed from the manifold.

The apparatus may further comprise a second sensor for sensing a second selected condition of the melt material through a second nozzle, the computer being interconnected to the second sensor for receiving a signal representative of the selected condition sensed by the second sensor, the computer including an algorithm utilizing a value corresponding to a signal received from the second sensor as a variable for controlling operation of an actuator for the second nozzle.

The seal surface of the at least one nozzle is preferably a radially disposed surface which makes compressed contact with the complementary surface of the mold surrounding the gate. The seal surface of the at least one nozzle is typically a longitudinally disposed tip end surface which makes compressed contact with the complementary surface of the mold surrounding the gate.

The sensor is preferably selected from the group consisting of a pressure transducer, a load cell, a valve pin position sensor, a temperature sensor, a flow meter and a barrel screw position sensor.

The pin is most preferably mounted in an aperture in a housing containing the channel, the aperture having a diameter equal to or greater than the maximum diameter circumferential surface of the bulbous protrusion of the pin.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is described in detail with reference to the following drawings depicting representative embodiments of the present invention, wherein:

Figure 1 is a partially schematic cross-sectional view of an injection molding system used in implementing an embodiment of the present invention;

Figure 2 is an enlarged fragmentary cross-sectional view of one side of the injection molding system of Figure 1;

Figure 3 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a plug is used for easy removal of the valve pin;

Figure 4 is an enlarged fragmentary cross-sectional view of an alternative embodiment of a system similar to Figure 1, in which a threaded nozzle is used;

Figure 5 is a view similar to Figure 4, showing an alternative embodiment in which a plug is used for easy removal of the valve pin;

Figure 5a is a generic view of the end of the nozzles shown in Figs 1-5;

Figure 5b is a close-up more detailed view of a portion of the nozzle end encircled by arrows 5b-5b shown in Fig. 5a;

Figure 5c is cross-sectional view of an alternative nozzle end configuration similar to the Figs. 5a and 5b configuration;

Figure 6 shows a fragmentary cross-sectional view of a system similar to Figure 1, showing an alternative embodiment in which a forward valve pin shut-off is used;

Figure 7 shows an enlarged fragmentary view of the embodiment of Figure 6, showing the valve pin in the open and closed positions, respectively;

Figure 8 is a cross-sectional view of an alternative embodiment of the present invention similar to Figure 6, in which a threaded nozzle is used with a plug for easy removal of the valve pin;

Figure 9 is an enlarged fragmentary view of the embodiment of Figure 8, in which the valve pin is shown in the open and closed positions;

Figure 10 is an enlarged view of an alternative embodiment of the valve pin, shown in the closed position;

Figure 11 is a fragmentary cross sectional view of an alternative embodiment of an injection molding system having flow control that includes a valve pin that extends to the gate; and

Figure 12 is an enlarged fragmentary cross-sectional detail of the flow control area;

Figure 13 is a side cross-section of the lower end of another nozzle having a straight valve pin;

Figure 13a is a view along lines 13a-13a of Fig. 13;

Figure 14 is a schematic side cross-sectional view of a sensor monitored injection molding system having rotary valves disposed in the manifold flow channels for controlling melt flow into a mold cavity;

Figure 15 is a top plan cross sectional view of one of rotary valves of Figure 14 along lines 15-15 showing the rotary valve in a shut off position;

Figure 16 is a side cross-sectional view of one of the rotary valves of Figure 14;

Figure 17 is top plan view of one of the rotary valves of Figure 14 showing limit stops for limiting the rotation of the rotary cylinder of the rotary valves;

Figure 18 is a top view of one of the drive actuator-controllers of Figure 14 showing the position of bolts for connecting the drive-actuator relative to the valve;

Figure 19 is a schematic side cross-sectional view of an alternative rotary valve flow controlled system showing a dual drive actuator which simultaneously drives/controls a rotary valve and a valve pin which is additionally used in the bore of one of the down bores feeding into the cavity of the mold;

Figure 20 is a more detailed view of the mechanical interconnection between the dual drive actuator of Figure 19 and the rotary valve and the valve pin;

Figure 21 is a schematic top view of a drive wheel component of the drive actuator of Figure 19 showing the gear mesh relationship between the drive wheel and the follower wheel of the rotary valve;

Figure 22 is a side cross-sectional view of a shaftless motor for use as an alternative actuator for a valve or other flow control mechanism in accordance with the invention, the motor having an axially movable screw for driving the flow controller;

Figure 23 is a side cross sectional view of a sensor monitored nozzle having a straight valve pin interconnected to a readily detachable actuator having a readily attachable and detachable valve pin, the actuator being fed with pressurized drive fluid by a manifold which commonly feeds pressurized drive fluid to a plurality of actuators;

Figure 24 is an exploded view of the actuator interconnection components to the manifold shown in Fig. 23;

Figure 25 is an exploded view of the actuator interconnection to the drive fluid manifold of Fig. 23;

Figure 26 is an isometric view of a modular embodiment of a pressurized drive fluid manifold showing a modular configuration for the manifold;

Figure 27 is an isometric close-up view of a modular arm and actuator interconnection according to the Fig. 26 embodiment showing the alignment of a modular manifold with the fluid input/output ports of the actuator;

Figure 28 is a schematic side cross-sectional view of a sensor monitored valve gated nozzle having an actuator fed by a drive fluid delivery manifold and a proportional valve mounted on the manifold above the valve for precisely controlling the delivery of drive fluid to the individual actuator from the manifold;

Figure 29 is a side cross-sectional view of an embodiment having an Edge-Gated nozzle tip having sensor feedback control loop control over the actuator;

Figure 30 is a more detailed close-up view of the interface between the edge gated nozzle tip of Fig. 29 and the gate area of a mold cavity;

Figure 31 is a side cross-sectional view of an embodiment of the invention having a defined volume reservoir disposed in the melt flow channel leading from the main injection screw to the output of an injection nozzle;

Figure 32 is a side cross-sectional view of valve having a curvilinear bulbous protrusion and an extended pin, the bulbous protrusion being in a flow shut-off position;

Figure 32A is a close-up view of the bulbous protrusion of Fig. 32;

Figure 33 is a view similar to Fig. 32 showing the bulbous protrusion in a flow controlling position;

Figure 33A is a close-up view of the bulbous protrusion position of Fig. 33;

Figure 34 is a view similar to Fig. 32 showing the bulbous protrusion in a downstream position and the distal tip end of the extended pin in a gate flow shut-off position;

Figure 34A is a close-up view of the bulbous protrusion position of Fig. 34;

Figure 35 is a side cross-sectional view of valve having a curvilinear bulbous protrusion, the bulbous protrusion being in a flow shut-off position and not having a gate shut off distal pin extension section;

Figure 36 is a view similar to Fig. 35 showing the bulbous protrusion in a flow controlling position;

Figure 37 is a side cross-sectional view of valve having a curvilinear bulbous protrusion, where the pin is mounted in an aperture in the hot runner which has a diameter equal to the diameter of the bulbous protrusion such that the pin may be withdrawn from the actuator and the hotrunner without removing the actuator from the housing or the mounting bushing from the hotrunner, and where the bulbous protrusion is in a flow shut-off position;

Figure 37A is a close-up view of the bulbous protrusion in the flow shut off position of Fig. 37;

Figure 38 is a view similar to Fig. 37 showing the bulbous protrusion in a downstream flow controlling position;

Figure 38A is a close-up view of the bulbous protrusion in the flow controlling position of Fig. 38;

Figure 39 is a schematic side cross-sectional view of an embodiment of a pin having a bulbous protrusion with a maximum diameter circumferential section which has straight surfaces, e.g. cylindrical, which complementarily mate with a complementary straight cylindrical surface on the interior of the flow channel at a throat section;

Figure 40 is a schematic side cross-sectional view of an embodiment showing a bulbous protrusion similar to Fig. 39 but where the controlling flow position is upstream of the throat section of the channel and the flow shut-off position is achieved or reached by forward or upstream movement of the pin from the position shown in Fig. 40.

DETAILED DESCRIPTION

Figures 1-2 show one embodiment of an injection molding system according to the present invention having two nozzles 21, 23 the plastic flow through which are to be controlled dynamically according to an algorithm as described below. Although only two nozzles are shown in Figs. 1-2, the invention contemplates simultaneously controlling the material flow through at least two and also through a plurality of more than two nozzles. In the embodiment shown, the injection molding system 1 is a multi-gate single cavity system in which melt material 3 is injected into a cavity 5 from the two gates 7 and 9. Melt material 3 is injected from an injection molding machine 11 through an extended inlet 13 and into a manifold 15. Manifold 15 distributes the melt through channels 17 and 19. Although a hot runner system is shown in which plastic melt is injected, the invention is applicable to other types of injection systems in which it is useful to control the rate at which a material (e.g., metallic or composite materials) is delivered to a cavity.

Melt is distributed by the manifold through channels 17 and 19 and into bores 18 and 20 of the two nozzles 21 and 23, respectively. Melt is injected out of nozzles 21 and 23 and into cavity 5 (where the part is formed) which is formed by mold plates 25 and 27. Although a multi-gate single-cavity system is shown, the invention is not limited to this type of system, and is also applicable to, for example, multi-cavity systems, as discussed in greater detail below.

The injection nozzles 21 and 23 are received in respective wells 28 and 29 formed in the mold plate 27. The nozzles 21 and 23 are each seated in support rings 31 and 33. The support rings serve to align the nozzles with the gates 7 and 9 and insulate the nozzles from the mold. The manifold 15 sits atop the rear end of the nozzles and maintains sealing contact with the nozzles via compression forces exerted on the assembly by clamps (not shown) of the injection molding machine. An O-ring 36 is provided to prevent melt leakage between the nozzles and the manifold. A dowel 73 centers the manifold on the mold plate 27. Dowels 32 and 34 prevent the nozzle 23 and support ring 33, respectively, from rotating with respect to the mold 27.

In the embodiment shown in Figs. 1-3 an electric band heater 35 for heating the nozzles is shown. In other embodiments, heat pipes, such as those disclosed in U.S. Patent No. 4,389,002, the disclosure of which is incorporated herein by reference and discussed below, may be disposed in a nozzle and used alone or in conjunction with a band heater 35. The heater is used to maintain the melt material at its processing temperature as far up to the point of exit through/into gates 7 and 9 as possible. As shown, the manifold is heated to elevated temperatures sufficient to maintain the plastic or other fluid which is injected into the manifold distribution ducts 17, 19 at a preferred preselected flow and processing temperature. A plurality of heat pipes 4 (only one of which is shown in Figs 2, 3) are preferably disposed throughout the

manifold/hotrunner 15 so as to more uniformly heat and maintain the manifold at the desired processing temperature.

The mold plate or body 27 is, on the other hand, typically cooled to a preselected temperature and maintained at such cooled temperature relative to the temperature of the manifold 15 via cooling ducts 2 through which water or some other selected fluid is pumped during the injection molding process in order to effect the most efficient formation of the part within the mold cavity.

As shown in Figs. 1-5b, the injection nozzle(s) is/are mounted within well 29 so as to be held in firmly stationary alignment with the gate(s) 7, 9 which lead into the mold cavities. The mounting of the heated nozzle(s) is/are arranged so as to minimize contact of the nozzle(s) body and its associated components with the cooled mold plate 27 but at the same time form a seal against fluid leakage back into an insulative air space in which the nozzle is disposed thus maintaining the fluid pressure within the flow bore or channel against loss of pressure due to leakage. Figs 5a, 5b show a more detailed schematic view of the nozzle mountings of Figs. 1-5. As shown, there is preferably provided a small, laterally disposed, localized area 39a at the end of the nozzle for making compressed contact with a complementary surface 27a of the plate 27. This area of compressed contact acts both as a mount for maintaining the nozzle in a stationary, aligned and spaced apart from the plate 27 relationship and also as a seal against leakage of fluid back from the gate area into the insulative space 29 in the well left between the nozzle and the mold plate 27. In the embodiment shown the mating area of the nozzle 39a is a laterally facing surface although a longitudinally facing surface may also be selected for effecting such a seal. The dimensions of the inner and outer pieces are machined so that compression mating between the laterally facing nozzle surface 39a and plate surface 27a occurs upon heating of the nozzle to

its operating temperature which expands both laterally and longitudinally upon heating. The lateral mating surfaces 27a and 39a typically enables more ready machining of the parts, although compression mating between axially or longitudinally facing surfaces such as 39b and 27b can be provided for in the alternative. As shown in Figs 5a, 5b an insulative space 6a is also left between the most distal tip end surfaces of the nozzle and the mold such that as little direct contact as possible between the heated nozzle and the relatively cooler plate 27 is made.

Another example of lateral surface mating upon heating of the nozzle to operating process temperature can be seen in the embodiment shown in Figs 13, 13a. In this elastically deformable nozzle which is described in detail in US application serial number 09/315,469, the disclosure of which is incorporated herein by reference, inner nozzle piece 37 is forced downwardly DF, Figs. 13, 13a upon heating of the apparatus to operating temperature whereby the undersurface 15a of manifold 15 compresses downwardly against the upper surface 37a of piece 37 causing the undersurface of step 37b to press downwardly DF, Fig. 13a, on the upper surface 39a of piece 39 which in turn causes the leg portion 39c, Fig 13a, to pivot P laterally and thus cause compressed mating between laterally facing surface 39d and laterally facing surface 27a of mold 27 to occur thus forming a seal against fluid leakage.

In an alternative embodiment shown in Fig. 5c, the nozzles may be machined or configured so as to leave a predetermined gap between or a non-compressed mating between two axially or longitudinally facing surfaces 27b and 39c (in the initially assembled cold state) which gap will close upon heating the apparatus up to its operating plastic processing temperature such that the two surfaces 27b and 39c mate under compression to form a seal. As shown in Fig. 5c the insulative air gap 6a is maintained along the lateral edges of the outer piece 39 of the nozzle into which plastic melt does not flow by virtue of a seal which is formed between the surfaces

27b and 39c upon heating of the apparatus up. The same sort of longitudinal/axial seal may be formed using another alternative nozzle embodiment such as disclosed in US Patent No. 5,885,628, the disclosure of which is incorporated herein by reference, where the outer nozzle piece forms a flange like member around the center portion of the nozzle. In any case, a relatively small surface on the outside of the distal tip end of the nozzles makes compression contact with a surface of the mold plate by virtue of thermally induced expansion of the nozzles such that a seal against melt flow is formed.

The nozzles may comprise a single unitary piece or, as shown in the embodiments in Figs. 1-5b, the nozzles 21 and 23 may comprise two (or more) separate unitary pieces such as insert 37 and tip 39. The insert 37 is typically made of a material (for example beryllium copper) having a relatively high thermal conductivity in order to maintain the melt at its most preferred high processing temperature as far up to the gate as possible by imparting heat to the melt from the heater 35 and/or via heat pipes as discussed below. In the embodiments shown, the outer tip piece 39 is used to form the seal with the mold plate 27 and preferably comprises a material (for example titanium alloy or stainless steel) having a substantially lower thermal conductivity relative to the material comprising the inner piece 37 so as reduce/minimize heat transfer from the nozzle (and manifold) to the mold as much as possible.

A seal or ring R, Figs. 5a-5c, is provided in the embodiment shown between the inner 37 and outer 39 pieces. As described in US Patent Nos. 5,554,395 and 5,885,628, the disclosures of which are incorporated herein by reference, seal/ring R serves to insulate the two nozzle pieces 37, 39 from each other minimizing heat transfer between the two pieces and also by providing an insulative air gap 6b between the two nozzle pieces. The seal R comprises a member made of a metallic alloy or like material which may be substantially less heat conductive than the material

of which pieces 37, 39 are comprised. The sealing member R is preferably a thin-walled, substantially resilient structure, and may be adapted for engagement by the seal mounting means so as to be carried by the nozzle piece 39. The sealing member R extends a preselected distance outwardly from the tip portion of the bushing so as to form a sealing engagement along a limited contact area located on the adjoining bore in the mold when the nozzle is operatively disposed therein. More particularly, in one preferred embodiment, it is contemplated that the sealing member R will include at least one portion having a partially open, generally C-shaped or arc-shaped transverse cross-section. Accordingly, the sealing member R may be formed as an O-ring, or as an O-ring defining spaced, aligned openings in its surface. Similarly, the sealing member may be formed as an O-ring having an annular portion removed from its inner wall so as to form a C-shaped or arc-shaped cross-sectional structure. Further, the sealing member may have a generally V-shaped or U-shaped or other cross-section which is dimensionally compatible with the mating areas with nozzle pieces 37, 39, if desired. In addition, the sealing member may be formed as a flexible length of hollow tubing or a flexible length of material having the desired generally C-shaped or arc-shaped or V-shaped or U-shaped transverse cross-section. Other possible configurations also will occur to those skilled in the art in view of the following detailed description of the present invention

As shown in Fig 5a, the nozzles may include one or more heat pipes 4a embedded within the body of the nozzles for purposes of more efficiently and uniformly maintaining the nozzle at an elevated temperature. In the Fig. 5a embodiment the heat pipes 4a are disposed in the nozzle body part 23 which typically comprises a high strength tool steel which has a predetermined high heat conductivity and strength. The heat pipes 4 mounted in the manifold, Figs. 2,3 and heat pipes 4a, Fig. 5a, preferably comprise sealed tubes comprised of copper or steel within which

any vaporizable and condensable liquid such as water is enclosed. Mercury may be used as the vaporizable heat transferring medium in the heat pipes 4, 4a, however, it is more preferable to use an inert liquid material such as water. One drawback to the use of water is that there can be a tendency for a reaction to occur between the iron in the steel and the water whereby the iron combines with the oxygen of the water leaving a residue of hydrogen which is an incondensable gas under the conditions of operation of the heat pipe. The presence of hydrogen in the heat pipe is deleterious to its effective operation. For the purposes of this invention any material, such as iron or an alloy of iron, which tends to release hydrogen from water is referred to as "water incompatible material."

The use of high strength steel is made practicable by plating or otherwise covering the interior wall of each heat pipe with a material which is non-reactive with water. Examples of such materials are nickel, copper, and alloys of nickel and copper, such as monel. Such materials are referred to herein as "water compatible materials." The inner wall of each heat pipe 4, 4a is preferably plated with a water compatible material, preferably nickel. Such plating is preferably made thick enough to be impermeable to water and water vapor. A wick structure 4c is inserted into each heat pipe, the wick typically comprising a water compatible cylindrical metal screen which is forced into and tightly pressed against the interior wall of a heat pipe. The wick preferably comprises a water compatible material such as monel. The elevated temperature at which the manifold and/or nozzles are maintained during an injection cycle typically ranges between about 200 and about 400 degrees centigrade. The vapor pressure of water at these temperatures, although quite high, is readily and safely contained with the enclosed tubular heat pipes. In practice, less than the total volume of the enclosed heat pipes is filled with the selected fluid, typically less than about 70% of such volume, and more typically less than 50%.

Following the insertion of the water, the outer end of each heat pipe is sealed by conventional means. In a preferred embodiment the tubular heat pipes are sealed at one end via a plug as described in US Patent No. 4,389,002, the disclosure of which is incorporated herein by reference. In operation, the fluid contained within the heat pipes 4, 4a is vaporized by heat conduction from the manifold. The fluid vaporizes and travels to each portion of the heat pipe from which heat is being extracted and the vapor condenses at each such portion to yield up its heat of condensation to maintain the entire length of the heat pipe at the same temperature. The vaporization of water from the inner end of the wick structure 4c creates a capillary attraction to draw condensed water from the rest of the wick structure back to the evaporator portion of the wick thus completing the cycle of water flow to maintain the heat pipe action. Where a plurality of heat pipes are disposed around the nozzle, there is maintained a uniform temperature around the axis X of the nozzle bores, particularly in embodiments where the heat pipes are disposed longitudinally as close to the exit end of the nozzle as possible.

In one embodiment, Figs. 1-5, a valve pin 41 having a tapered head 43 controllably engagable with a surface upstream of the exit end of the nozzle may be used to control the rate of flow of the melt material to and through the respective gates 7 and 9. The valve pin reciprocates through the flow channel 100 in the manifold 15. A valve pin bushing 44 is provided to prevent melt from leaking along stem 102 of the valve pin. The valve pin bushing is held in place by a threadably mounted cap 46. The valve pin is opened at the beginning of the injection cycle and closed at the end of the cycle. During the cycle, the valve pin can assume intermediate positions between the fully open and closed positions, in order to decrease or increase the rate of flow of the melt. The head includes a tapered portion 45 that forms a gap 81 with a surface 47 of the bore 19 of the manifold. Increasing or decreasing the size of the gap by displacing the valve pin

correspondingly increases or decreases the flow of melt material to the gate. When the valve pin is closed the tapered portion 45 of the valve pin head contacts and seals with the surface 47 of the bore of the manifold.

Figure 2 shows the head of the valve pin in a Phantom dashed line in the closed position and a solid line in the fully opened position in which the melt is permitted to flow at a maximum rate. To reduce the flow of melt, the pin is retracted away from the gate by an actuator 49, to thereby decrease the width of the gap 81 between the valve pin and the bore 19 of the manifold.

The actuator 49 (for example, the type disclosed in application serial no. 08/874,962, the disclosure of which is incorporated herein by reference) is mounted in a clamp plate 51 which covers the injection molding system 1. In the embodiment shown, the actuator 49 is a hydraulic actuator, however, pneumatic or electronic actuators can also be used. Other actuator configurations having ready detachability may also be employed such as those described in US application serial nos. 08/972,277 and 09/081,360 and PCT application US99/11391, the disclosures of all of which are incorporated herein by reference. An electronic or electrically powered actuator may also be employed such as disclosed in US application serial no. 09/187,974, the disclosure of which is incorporated herein by reference. In the embodiment shown, the actuator 49 includes a hydraulic circuit that includes a movable piston 53 in which the valve pin 41 is threadably mounted at 55. Thus, as the piston 53 moves, the valve pin 41 moves with it. The actuator 49 includes hydraulic lines 57 and 59 which are controlled by servo valves 1 and 2. Hydraulic line 57 is energized to move the valve pin 41 toward the gate to the open position, and hydraulic line 59 is energized to retract the valve pin away from the gate toward the close position. An actuator cap 61 limits longitudinal movement in the vertical

direction of the piston 53. O-rings 63 provide respective seals to prevent hydraulic fluid from leaking out of the actuator. The actuator body 65 is mounted to the manifold via screws 67.

In embodiments where a pneumatically or electrically powered actuator is employed, suitable pneumatic (air supply) or electrical power inputs to the actuator are provided, such inputs being controllable to precisely control the movement of the actuator via the same computer generated signals which are output from the PID1 and PID2 controllers and the same or similar control algorithm/program used in the CPU of FIG. 1 such that precise control of the movement of the valve pin used to control plastic flow is achieved according to the predetermined algorithm selected for the particular application.

In the embodiment shown, a pressure transducer 69 is used to sense the pressure in the manifold bore 19 downstream of the valve pin head 43. In operation, the conditions sensed by the pressure transducer 69 associated with each nozzle are fed back to a control system that includes controllers PID 1 and PID 2 and a CPU shown schematically in Figure 1. The CPU executes a PID (proportional, integral, derivative) algorithm which compares the sensed pressure (at a given time) from the pressure transducer to a programmed target pressure (for the given time). The CPU instructs the PID controller to adjust the valve pin using the actuator 49 in order to mirror the target pressure for that given time. In this way a programmed target pressure profile for an injection cycle for a particular part for each gate 7 and 9 can be followed.

As to each separate nozzle, the target pressure or pressure profile may be different, particularly where the nozzles are injecting into separate cavities, and thus separate algorithms or programs for achieving the target pressures at each nozzle may be employed. As can be readily imagined, a single computer or CPU may be used to execute multiple programs/algorithms for

each nozzle or separate computers may be utilized. The embodiment shown in Fig. 1 is shown for purposes of ease of explanation.

Although in the disclosed embodiment the sensed condition is pressure, other sensed conditions can be used which relate to melt flow rate. For example, the position of the valve pin or the load on the valve pin could be the sensed condition. If so, a position sensor or load sensor, respectively, could be used to feed back the sensed condition to the PID controller. In the same manner as explained above, the CPU would use a PID algorithm to compare the sensed condition to a programmed target position profile or load profile for the particular gate to the mold cavity, and adjust the valve pin accordingly. Similarly the location of the sensor and the sensed condition may be other than in the nozzle itself. The location of the measurement may, for example, be somewhere in the cavity of the mold or upstream of the nozzle somewhere in the manifold flow channel or even further upstream in the melt flow.

Melt flow rate is directly related to the pressure sensed in bore 19. Thus, using the controllers PID 1 and PID 2, the rate at which the melt flows into the gates 7 and 9 can be adjusted during a given injection molding cycle, according to the desired pressure profile. The pressure (and rate of melt flow) is decreased by retracting the valve pin and decreasing the width of the gap 81 between the valve pin and the manifold bore, while the pressure (and rate of melt flow) is increased by displacing the valve pin toward the gate 9, and increasing the width of the gap 81. The PID controllers adjust the position of the actuator piston 53 by sending instructions to servo valves 1 and 2.

By controlling the pressure in a single cavity system (as shown in Figure 1) it is possible to adjust the location and shape of the weld line formed when melt flow 75 from gate 7 meets melt flow 77 from gate 9 as disclosed in U.S. Patent No. 5,556,582. However, the invention also

is useful in a multi-cavity system. In a multi-cavity system the invention can be used to balance fill rates and packing profiles in the respective cavities. This is useful, for example, when molding a plurality of like parts in different cavities. In such a system, to achieve a uniformity in the parts, the fill rates and packing profiles of the cavities should be as close to identical as possible. Using the same programmed pressure profile for each nozzle, unpredictable fill rate variations from cavity to cavity are overcome, and consistently uniform parts are produced from each cavity.

Another advantage of the present invention is seen in a multi-cavity system in which the nozzles are injecting into cavities which form different sized parts that require different fill rates and packing profiles. In this case, different pressure profiles can be programmed for each respective controller of each respective cavity. Still another advantage is when the size of the cavity is constantly changing, i.e., when making different size parts by changing a mold insert in which the part is formed. Rather than change the hardware (e.g., the nozzle) involved in order to change the fill rate and packing profile for the new part, a new program is chosen by the user corresponding to the new part to be formed.

The embodiment of Figures 1 and 2 has the advantage of controlling the rate of melt flow away from the gate inside manifold 15 rather than at the gates 7 and 9. Controlling the melt flow away from the gate enables the pressure transducer to be located away from the gate (in Figures 1-5). In this way, the pressure transducer does not have to be placed inside the mold cavity, and is not susceptible to pressure spikes which can occur when the pressure transducer is located in the mold cavity or near the gate. Pressure spikes in the mold cavity result from the valve pin being closed at the gate. This pressure spike could cause an unintended response from the

control system, for example, an opening of the valve pin to reduce the pressure -- when the valve pin should be closed.

Avoidance of the effects of a pressure spike resulting from closing the gate to the mold makes the control system behave more accurately and predictably. Controlling flow away from the gate enables accurate control using only a single sensed condition (e.g., pressure) as a variable. The '582 patent disclosed the use of two sensed conditions (valve position and pressure) to compensate for an unintended response from the pressure spike. Sensing two conditions resulted in a more complex control algorithm (which used two variables) and more complicated hardware (pressure and position sensors).

Another advantage of controlling the melt flow away from the gate is the use of a larger valve pin head 43 than would be used if the valve pin closed at the gate. A larger valve pin head can be used because it is disposed in the manifold in which the melt flow bore 19 can be made larger to accommodate the larger valve pin head. It is generally undesirable to accommodate a large size valve pin head in the gate area within the end of the nozzle 23, tip 39 and insert 37. This is because the increased size of the nozzle, tip and insert in the gate area could interfere with the construction of the mold, for example, the placement of water lines within the mold which are preferably located close to the gate. Thus, a larger valve pin head can be accommodated away from the gate.

The use of a larger valve pin head enables the use of a larger surface 45 on the valve pin head and a larger surface 47 on the bore to form the control gap 81. The more "control" surface (45 and 47) and the longer the "control" gap (81) -- the more precise control of the melt flow rate and pressure can be obtained because the rate of change of melt flow per movement of the valve pin is less. In Figures 1-3 the size of the gap and the rate of melt flow is adjusted by

adjusting the width of the gap, however, adjusting the size of the gap and the rate of material flow can also be accomplished by changing the length of the gap, i.e., the longer the gap the more flow is restricted. Thus, changing the size of the gap and controlling the rate of material flow can be accomplished by changing the length or width of the gap.

The valve pin head includes a middle section 83 and a forward cone shaped section 95 which tapers from the middle section to a point 85. This shape assists in facilitating uniform melt flow when the melt flows past the control gap 81. The shape of the valve pin also helps eliminates dead spots in the melt flow downstream of the gap 81.

Figure 3 shows another aspect in which a plug 87 is inserted in the manifold 15 and held in place by a cap 89. A dowel 86 keeps the plug from rotating in the recess of the manifold that the plug is mounted. The plug enables easy removal of the valve pin 41 without disassembling the manifold, nozzles and mold. When the plug is removed from the manifold, the valve pin can be pulled out of the manifold where the plug was seated since the diameter of the recess in the manifold that the plug was in is greater than the diameter of the valve pin head at its widest point. Thus, the valve pin can be easily replaced without significant downtime.

Figures 4 and 5 show additional alternative embodiments of the invention in which a threaded nozzle style is used instead of a support ring nozzle style. In the threaded nozzle style, the nozzle 23 is threaded directly into manifold 15 via threads 91. Also, a coil heater 93 is used instead of the band heater shown in Figures 1-3. The threaded nozzle style is advantageous in that it permits removal of the manifold and nozzles (21 and 23) as a unitary element. There is also less of a possibility of melt leakage where the nozzle is threaded on the manifold. The support ring style (Figures 1-3) is advantageous in that one does not need to wait for the

manifold to cool in order to separate the manifold from the nozzles. Figure 5 also shows the use of the plug 87 for convenient removal of valve pin 41.

Figures 6-10 show an alternative embodiment of the invention in which a "forward" shutoff is used rather than a retracted shutoff as shown in Figures 1-5. In the embodiment of Figures 6 and 7, the forward cone-shaped tapered portion 95 of the valve pin head 43 is used to control the flow of melt with surface 97 of the inner bore 20 of nozzle 23. An advantage of this arrangement is that the valve pin stem 102 does not restrict the flow of melt as in Figures 1-5. As seen in Figures 1-5, the clearance 81 between the stem 102 and the bore 19 of the manifold is not as great as the clearance 98 in Figures 6 and 7. The increased clearance 98 in Figures 6-7 results in a lesser pressure drop and less shear on the plastic.

In Figures 6 and 7 the control gap 98 is formed by the front cone-shaped portion 95 and the surface 97 of the bore 20 of the rear end of the nozzle 23. The pressure transducer 69 is located downstream of the control gap -- thus, in Figures 6 and 7, the nozzle is machined to accommodate the pressure transducer as opposed to the pressure transducer being mounted in the manifold as in Figures 1-5.

Figure 7 shows the valve pin in solid lines in the open position and Phantom dashed lines in the closed position. To restrict the melt flow and thereby reduce the melt pressure, the valve pin is moved forward from the open position towards surface 97 of the bore 20 of the nozzle which reduces the width of the control gap 98. To increase the flow of melt the valve pin is retracted to increase the size of the gap 98.

The rear 45 of the valve pin head 43 remains tapered at an angle from the stem 102 of the valve pin 41. Although the surface 45 performs no sealing function in this embodiment, it is still tapered from the stem to facilitate even melt flow and reduce dead spots.

As in Figures 1-5, pressure readings are fed back to the control system (CPU and PID controller), which can accordingly adjust the position of the valve pin 41 to follow a target pressure profile. The forward shut-off arrangement shown in Figures 6 and 7 also has the advantages of the embodiment shown in Figures 1-5 in that a large valve pin head 43 is used to create a long control gap 98 and a large control surface 97. As stated above, a longer control gap and greater control surface provides more precise control of the pressure and melt flow rate.

Figures 8 and 9 show a forward shutoff arrangement similar to Figures 6 and 7, but instead of shutting off at the rear of the nozzle 23, the shut-off is located in the manifold at surface 101. Thus, in the embodiment shown in Figures 8 and 9, a conventional threaded nozzle 23 may be used with a manifold 15, since the manifold is machined to accommodate the pressure transducer 69 as in Figures 1-5. A spacer 88 is provided to insulate the manifold from the mold. This embodiment also includes a plug 87 for easy removal of the valve pin head 43.

Figure 10 shows an alternative embodiment of the invention in which a forward shutoff valve pin head is shown as used in Figures 6-9. However, in this embodiment, the forward cone-shaped taper 95 on the valve pin includes a raised section 103 and a recessed section 104. Ridge 105 shows where the raised portion begins and the recessed section ends. Thus, a gap 107 remains between the bore 20 of the nozzle through which the melt flows and the surface of the valve pin head when the valve pin is in the closed position. Thus, a much smaller surface 109 is used to seal and close the valve pin. The gap 107 has the advantage in that it assists opening of the valve pin which is subjected to a substantial force F from the melt when the injection machine begins an injection cycle. When injection begins melt will flow into gap 107 and provide a force component F1 that assists the actuator in retracting and opening the valve pin. Thus, a smaller actuator, or the same actuator with less hydraulic pressure applied, can be used

because it does not need to generate as much force in retracting the valve pin. Further, the stress forces on the head of the valve pin are reduced.

Despite the fact that the gap 107 performs no sealing function, its width is small enough to act as a control gap when the valve pin is open and correspondingly adjust the melt flow pressure with precision as in the embodiments of Figures 1-9.

Figures 11 and 12 show an alternative hot-runner system having flow control in which the control of melt flow is still away from the gate as in previous embodiments. Use of the pressure transducer 69 and PID control system is the same as in previous embodiments. In this embodiment, however, the valve pin 41 extends past the area of flow control via extension 110 to the gate. The valve pin is shown in solid lines in the fully open position and in Phantom dashed lines in the closed position. In addition to the flow control advantages away from the gate described above, the extended valve pin has the advantage of shutting off flow at the gate with a tapered end 112 of the valve pin 41.

Extending the valve pin to close the gate has several advantages. First, it shortens injection cycle time. In previous embodiments thermal gating is used. In thermal gating, plastication does not begin until the part from the previous cycle is ejected from the cavity. This prevents material from exiting the gate when the part is being ejected. When using a valve pin, however, plastication can be performed simultaneously with the opening of the mold when the valve pin is closed, thus shortening cycle time by beginning plastication sooner. Using a valve pin can also result in a smoother gate surface on the part.

The flow control area is shown enlarged in Figure 12. In solid lines the valve pin is shown in the fully open position in which maximum melt flow is permitted. The valve pin includes a convex surface 114 that tapers from edge 128 of the stem 102 of the valve pin 41 to a

throat area 116 of reduced diameter. From throat area 116, the valve pin expands in diameter in section 118 to the extension 110 which extends in a uniform diameter to the tapered end of the valve pin.

In the flow control area the manifold includes a first section defined by a surface 120 that tapers to a section of reduced diameter defined by surface 122. From the section of reduced diameter the manifold channel then expands in diameter in a section defined by surface 124 to an outlet of the manifold 126 that communicates with the bore of the nozzle 20. Figures 11 and 12 show the support ring style nozzle similar to Figures 1-3. However, other types of nozzles may be used such as, for example, a threaded nozzle as shown in Figure 8.

As stated above, the valve pin is shown in the fully opened position in solid lines. In Figure 12, flow control is achieved and melt flow reduced by moving the valve pin 41 forward toward the gate thereby reducing the width of the control gap 98. Thus, surface 114 approaches surface 120 of the manifold to reduce the width of the control gap and reduce the rate of melt flow through the manifold to the gate.

To prevent melt flow from the manifold bore 19, and end the injection cycle, the valve pin is moved forward so that edge 128 of the valve pin, i.e., where the stem 102 meets the beginning of curved surface 114, will move past point 130 which is the beginning of surface 122 that defines the section of reduced diameter of the manifold bore 19. When edge 128 extends past point 130 of the manifold bore melt flow is prevented since the surface of the valve stem 102 seals with surface 122 of the manifold. The valve pin is shown in dashed lines where edge 128 is forward enough to form a seal with surface 122. At this position, however, the valve pin is not yet closed at the gate. To close the gate the valve pin moves further forward, with the

surface of the stem 102 moving further along, and continuing to seal with, surface 122 of the manifold until the end 112 of the valve pin closes with the gate.

In this way, the valve pin does not need to be machined to close the gate and the flow bore 19 of the manifold simultaneously, since stem 102 forms a seal with surface 122 before the gate is closed. Further, because the valve pin is closed after the seal is formed in the manifold, the valve pin closure will not create any unwanted pressure spikes. Likewise, when the valve pin is opened at the gate, the end 112 of the valve pin will not interfere with melt flow, since once the valve pin is retracted enough to permit melt flow through gap 98, the valve pin end 112 is a predetermined distance from the gate. The valve pin can, for example, travel 6 mm. from the fully open position to where a seal is first created between stem 102 and surface 122, and another 6 mm. to close the gate. Thus, the valve pin would have 12 mm. of travel, 6 mm. for flow control, and 6 mm. with the flow prevented to close the gate. Of course, the invention is not limited to this range of travel for the valve pin, and other dimensions can be used.

Figs. 13 and 13a show a nozzle having a conventional straight cylindrical pin 41 which may be used as an alternative in conjunction with the automated systems described above. For example, pressure may be measured in the cavity itself by a sensor 69a and a program utilized in CPU, Fig. 1 which simply opens, Fig. 13a, and closes, Fig 13 the exit aperture or gate 9 upon sensing of a certain pressure so as to create certain pressure increase in the cavity when closed, or alternatively the tip end of the pin may be tapered (tapering shown in dashed lines 41b) in some fashion so as to vary the melt flow rate 20b, in accordance with a predetermined program depending on the sensor measurement 69a, as the pin 41 is moved into a predetermined closer proximity to the tip end surface 20a of bore 20 (complementary tapering of surface 20a not

shown) in a similar manner to the way the rate of melt flow may be varied using the tapered conical head 45 of the Figs. 2-5 embodiments.

Figs. 14-21 show an embodiment of the invention using rotary valves 200 as a mechanical component for controlling melt flow from a main feed channel 13 and common manifold feed channel 13d disposed in manifold 15 to a pair of down drop bores or nozzles 20d and exit apertures 9a in housings 20e which lead into cavity 9i. As shown, the rotary valves 200 comprise a rotatable shaft 202 having a melt passageway 204, the shaft being rotatably mounted in outer bearing housings 206. As shown the outer bearing 206 has a converging/diverging passageway 201 to match the inner shaft passageway 204. The rotary shaft 202 is rotatably drivable by its interconnection to actuator 208 which may comprise an electrically, pneumatically, hydraulically or mechanically powered mechanism which is typically mechanically interconnected to shaft 202. Automatic control of the actuators is effected in the same manner as described above via CPU and PID1 and PID2 controllers wherein signals are sent 210 from sensors 69 to the PID controllers and processed via CPU which, according to a predetermined algorithm signals the PID controllers to instruct actuators 208 to adjust the rotation of passageways 204 so as to vary the rate of melt flow through passageways 204 to achieve the predetermined target pressure or pressure profile at the position of sensors 69. Melt flow through passageways 204 can be precisely varied depending on the position of rotation of shaft 202 within bearings 206. As shown in Fig. 15, passageway 204c in the position shown is fully closed off from manifold passageway 201 and flow is completely stopped. As can be readily imagined, rotation of shaft 202, Fig. 15 in direction 202a will eventually open a leading edge of passageway 204 into open communication with manifold passageway 201 allowing melt to flow and gradually increase to a maximum flow when the passageway 204 reaches the

position 204o, Fig. 15. As described above with reference to other embodiments, the nozzle bores 20d may exit into a single cavity 9i or may exit into separate cavities (not shown).

Figs. 16-17 show mechanical limit stops that may be employed whereby prismatic stops 212, 213 attached to the bearing housing 206 serve to engage radial stops 215 of stop member 214 which is attached to the top of shaft 202 and thus serve to limit the rotational travel of shaft 202 in directions 202a and 202b.

Figs. 19-21 show an alternative embodiment where the actuators 208 commonly drive both a rotary valve 200 and a valve pin 41. As shown the valve pins 41 can be arranged so as to reciprocate along their axes X between open 41' and closed 41 aperture 9a positions simultaneously with shaft 202 being controllably rotated. Such simultaneous drive is accomplished via drive wheel 220, Figs. 20-21, whose gear teeth are meshed with gear teeth 226 of wheel 218 and the screwable engagement of the threaded head 234 of pins 41, 41' in the shafts 236 of driven wheels 220. As can be readily imagined as shaft 236 is rotated either clockwise or counterclockwise 24, pin 41' will be displaced either up or down 232 simultaneously with rotation of shaft 202 and its associated passageway 204. During a typical operation, the rotary valve may fully stop the melt flow prior to the valve pin closing at the exit 9a. Similarly, the valve pin may open access to the mold cavity 9i prior to the rotary valve permitting melt through the passageway 204.

Fig. 22 shows an example of an electrically powered motor which may be used as an actuator 301, in place of a fluid driven mechanism, for driving a valve pin or rotary valve or other nozzle flow control mechanism. In the embodiment shown in Figs. 22 a shaftless motor 300 mounted in housing 302 has a center ball nut 304 in which a screw 306 is screwably received for controlled reciprocal driving 308 of the screw 308a along axis X. Other motors

which have a fixed shaft in place of the screw may also be employed as described more fully in US application serial no. 09/187,974, the disclosure of which is incorporated herein by reference. As shown in the Fig. 22 embodiment the nut 304 is rigidly interconnected to magnet 310 and mounting components 310a, 310b which are in turn fixedly mounted on the inner race of upper rotational bearing 312 and lower rotational bearing 314 for rotation of the nut 304 relative to housing 302 which is fixedly interconnected to the manifold 15 of the injection molding machine. The axially driven screw 308a is fixedly interconnected to valve pin 41 which reciprocates 308 along axis X together with screw 308a as it is driven. As described more fully below, pin 41 is preferably readily detachably interconnected to the moving component of the particular actuator being used, in this case screw 308a. In the Fig. 22 embodiment, the head 41a of pin 41 is slidably received within a complementary lateral slot 321 provided in interconnecting component 320. The housing 302 may be readily detached from manifold 15 by unscrewing bolts 342 and lifting the housing 302 and sliding the pin head 41a out of slot 321 thus making the pin readily accessible for replacement.

As can be readily imagined other motors may be employed which are suitable for the particular flow control mechanism which is disposed in the flow channel of the manifold or nozzle, e.g. valve pin or rotary valve. For example, motors such as a motor having an axially fixed shaft having a threaded end which rotates together with the other rotating components of the actuator 301 and is screwably received in a complementary threaded nut bore in pin interconnecting component 320, or a motor having an axially fixed shaft which is otherwise screwably interconnected to the valve pin or rotary valve may be employed.

Controlled rotation 318 of screw 308a, Fig 22, is achieved by interconnection of the motor 300 to a motor controller 316 which is in turn interconnected to the CPU, the algorithm of

which (including PID controllers) controls the on/off input of electrical energy to the motor 300, in addition to the direction and speed of rotation 318 and the timing of all of the foregoing. Motor controller 316 may comprise any conventional motor control mechanism(s) which are suitable for the particular motor selected. Typical motor controllers include an interface 316a for processing/interpreting signals received from the CPU; and, the motor controllers typically comprise a voltage, current, power or other regulator receiving the processed/interpreted signals from interface 316a and regulates the speed of rotation of the motor 300 according to the instruction signals received.

Figs. 23, 24 show another embodiment of the invention where a readily detachable valve pin 41 interconnection is shown in detail. Fig. 23 shows a nozzle 21a having a configuration similar in design to the nozzle configuration of Fig. 13. As shown the nozzle 21a is mounted in an aperture in a mold plate 27 having an exit aperture aligned with gate 9a and a sensor 69a for measuring a material property in the cavity 9g which sends recordation signals to electronic controllers (including CPU, PID controllers or the like) for reciprocation of the pin 41 according to a predetermined program. In the embodiment shown the pin 41 is straight, however the pin 41 and the nozzle bore 20 may have other configurations such as shown/described with reference to Figs. 2-5 and the sensor 69 located in the nozzle bore 20 or other location in the path of the melt flow depending on the type and purpose of control desired for the particular application. As described above,, the ready detachability of the pin and actuator of the Figs. 23, 24 embodiment may also be adapted to an electric actuator such as described with reference to Fig. 22.

Figs. 23-28 illustrate another embodiment of the invention wherein certain components provide common fluid feed to a plurality fluid driven actuators and where certain components are readily attachable and/or detachable as described in US Patent No. 5,948,448, US application

serial number 09/081,360 filed May 19, 1998 and PCT US application serial number US99/11391 filed May 20, 1999, the disclosures of all of which are incorporated herein by reference. As shown in Figs. 23, 24 a fluid driven actuator 322 is fixedly mounted on a hotrunner manifold 324 having a melt flow channel 326 leading into nozzle bore 20. The actuator comprises a unitary housing 328 which sealably encloses a piston 332 having an O-Ring seal 334 which defines interior sealed fluid chambers, upper chamber 336 and lower chamber 338. The unitary housing 328 is spacedly mounted on and from the manifold 324 by spacers 340 and bolts 342 and an intermediate mounting plate 344 attached to the upper surface of the manifold 324. The heads 343 of the bolts 342 are readily accessible from the top surface 341 of the actuator housing 328 for ready detachment of the housing from plate 344 as shown in Fig. 24. Plate 344 is fixedly attached to the manifold via bolts 330.

The piston 332 has a stem portion 346, Figs. 23-25, which extends outside the interior of the sealed housing 328 and chambers 336, 338. At the end of the stem 346 a lateral slot 321 is provided for readily slidably receiving in a lateral direction the head 41a of the pin. As can be seen the bottom of the slot 321 has an aperture having a width less than the diameter of the pin head 41a such that once the pin head is slid laterally into the slot 321, the pin head is held axially within slot 321. In practice the pin head 41a and slot 321 are configured so that the pin head 41a fits snugly within the slot. As can be readily imagined, the pin head 41a can be readily slid out of the slot 321 upon detachment of the actuator 328, Fig. 24, thus obviating the prior art necessity of having to disassemble the actuator itself to obtain access to the pin head 41a. Once the actuator housing is detached, Fig. 24, the pin 41 is thus readily accessible for removal from and replacement in the manifold 324/nozzle bore 20.

In another embodiment of the invention, where hydraulic or pneumatic actuators are used to drive the pins or rotary valves of two or more nozzles, the drive fluid may be supplied by a common manifold or fluid feed duct. Such common fluid feed ducts are most preferably independent of the fluid driven actuators, i.e. the ducts do not comprise a housing component of the actuators but rather the actuators have a self contained housing, independent of the fluid feed manifold, which houses a sealably enclosed cavity in which a piston is slidably mounted. For example, as shown in Figs. 23-28, the fluid input/output ports 350, 352, 350a, 352a of independent actuators 322, 322a (Fig 28) are sealably mated with the fluid input output ports 354, 356, 354a, 356a of a fluid manifold 358, 358a which commonly delivers actuator drive fluid (such as oil or air) to the sealed drive chambers 336, 338, 336a, 338a of two or more actuators 322, 322a. Most preferably, the ports 354, 356 (or 354a, 356a) of the manifold 358 (or 358a) are sealably mated with their complementary actuator ports 350, 352 (350a, 352a) via compression mating of the undersurface 360 of the manifold 358 (358a) with the upper surface 341 of the actuators 322 (322a) as best shown in Fig. 25. Such compression mating may be achieved by initially connecting the manifold via bolt 363 and threaded holes 351 or similar means to the actuators 322 in their room temperature state (referred to as cold) with their mating surfaces in close or mating contact such that upon heating to operating temperature the manifold and actuators expand and the undersurfaces 360 and upper surfaces 341 compress against each other forming a fluid seal against leakage around the aligned ports 350/354 and 352/356. In most preferred embodiments, a compressible O-ring seal 364 is seated within a complementary receiving groove disposed around the mating area between the ports such that when the manifold and actuators are heated to operating temperature the O-ring is compressed between the

undersurface 360 and upper surface 341 thus forming a more reliable and reproducible seal with less precision in mounting alignment between the manifold and the actuators being required.

As shown in Figs 23, 25-28, the manifold(s) 322 has two feed ducts 365, 367 for delivery of pressurized actuator drive fluid to and from a master tank or other source (not shown) which ducts extend the length of the manifold 358 and commonly feed each actuator 322. In the embodiment shown in Figs. 26, 27 the manifold 358 can be constructed as a modular apparatus having a first distributor arm 358d generally adaptable to be mounted on a hotrunner manifold, to which one or more additional distributor arms 358c may be sealably attached 358e to fit/adapt to the specific configuration of the particular manifold or injection molding machine to be outfitted.

As can be readily imagined a plurality of actuators may also utilize a manifold plate which forms a structural component of one or more of the actuators and serves to deliver drive fluid commonly to the actuators, e.g. the manifold plate forms a structural wall portion of the housings of the actuators which serves to form the fluid sealed cavity within which the piston or other moving mechanism of the actuator is housed.

Precise control over the piston or other moving component of a fluid driven actuator such as actuator 322a, Fig. 28, actuator 49, Fig. 1, actuator 208, Fig. 14 (which more typically comprises an electrically driven actuator), or actuator 322, Figs 23-27 can be more effectively carried out with a proportional valve 370 as shown in Fig. 28, although other valve or drive fluid flow controllers may be employed.

In the Fig. 28 embodiment, a separate proportional valve 370 for each individual actuator 322a is mounted on a common drive fluid delivery manifold 358a. The manifold 358a has a single pressurized fluid delivery duct 372 which feeds pressurized drive fluid first into the

distributor cavity 370a of the valve 370. The pressurized fluid from duct 372 is selectively routed via left 375 or right 374 movement of plunger or spool 380 either through port 370b into piston chamber 338a or through port 370c into piston chamber 336a. The plunger or spool 380 is controllably movable to any left to right 375,_374 position within sealed housing 381 via servo drive 370e which receives control signals 382 from the CPU. The servo drive mechanism 370e typically comprises an electrically driven mechanism such as a solenoid drive, linear force motor or permanent magnet differential motor which is, in turn, controlled by and interconnected to CPU via interface 384 which interprets and communicates control signals from the CPU to the servo drive 370e. Restrictors or projections 370d and 370g of plunger/spool 380 are slidable over the port apertures 370 b and c to any desired degree such that the rate of flow of pressurized fluid from chamber 370a through the ports can be varied to any desired degree by the degree to which the aperture ports 370b, 370g are covered over or restricted by restrictors 370d, 370g. The valve 370 includes left and right vent ports which communicate with manifold fluid vent channels 371, 373 respectively for venting pressurized fluid arising from the left 375 or right 374 movement of the plunger/spool 380. Thus, depending on the precise positioning of restrictors 370d and 370g over apertures 370b and 370c, the rate and direction of axial movement of piston 385 and pin 41/head 43, 45 can be selectively varied and controlled which in turn controls the rate of melt material from manifold channel 19 through nozzle bore 20 and gate 9. The nozzle and pin 41, head 43, 45 and mounting component 87, 89 configurations shown in Fig. 28 correspond to the configurations shown in Fig. 5 and the description above with regard to the manner in which the melt material is controllable by such head 43, 45 configurations are applicable to the Fig. 28 embodiment. A pressurized fluid distributing valve and a fluid driven actuator having a configuration other than the proportional valve 370 and actuator shown in Fig.

28 may be utilized, the essential requirements of such components being that the valve include a fluid flow control mechanism which is capable of varying the rate of flow to the drive fluid chambers of the actuator to any desired rate and direction of flow into and out of the fluid drive chambers of the actuator.

In the embodiment shown in Figs. 29, 30, a nozzle 21 having a main bore 20 having a main axis X terminates in a gate interfacing bore having an axis Y which is not aligned with axis X. As shown the gate 9b of the mold having cavity 9c is an edge gate extending radially outward through a mold cavity plate 27 wherein the nozzle has a bore having a first portion 20 having an inlet for the plastic melt which is not in alignment with the edge gate and a second portion 20f extending radially outward from the first portion 20 terminating in the exit aperture of the radial bore 20f being in alignment with the edge gate 9b. In the preferred embodiment shown and as described more fully in US Patent No. 5,885,628, the disclosure of which is incorporated herein by reference, a small gap 9d is left between the radial tip end of the outer piece 39 of the nozzle and the surface of the mold plate around the cavity 9c such that it is possible for melt material to seep from groove 9k through the gap 9d and into the space 9j circumferentially surrounding the outer piece 39 where the gap 9d is selected to be small enough to prevent seepage of plastic melt backwards from space 9j into the groove area 9k and gate 9b area during ongoing or newly started up pressurized melt injection. The tip end of the nozzle as shown in Figs. 29, 30 comprises an outer 39 piece and an inner 37 piece having a gap 6b therebetween. The two pieces 37, 39 are mounted to nozzle body 410 which is mounted in thermal isolation from mold 27 together with nozzle pieces 37, 39 in a well 408 in the mold 27 via a collar 407 which makes limited mounting contact with the mold at small interface area 412 distally away from the gate 9b area. As shown surfaces 413, 415 of collar 407 support and align nozzle body 410 and its

associated/interconnected nozzle components 37, 39 such that the exit passage of nozzle component 37 along axis Y is aligned with the edge gate 9b of cavity 9c

As shown in Fig. 29 a sensor 69, such as a pressure transducer, records a property of the melt material in bore 20 downstream of the pin head 43 having a configuration similar to the embodiment shown in Fig. 3. The signal from sensor 69 is fed to the CPU and processed as described above with reference to other embodiments and instruction signals based on a predetermined algorithm are sent from the CPU to an interface 400 which sends interpreted signals to the driver 402, such as drive motor 402 which drives the drive fluid feed to actuator 322a (as shown having the same design as the actuator shown in Fig. 28 which is described in detail in US Patent No. 5,894,025, the disclosure of which is incorporated herein by reference). As shown in Fig. 30, a sensor 69d could be positioned so as to sense a property of the melt flow within the passage 20, or within the cavity 9c via a sensor 69i. As shown in Fig. 29 and as described above, the algorithm of the CPU is simultaneously controlling the operation of the actuator 420 associated with another nozzle (not shown) via sensor signals sent by a sensor associated with the other nozzle.

Fig. 31 shows an embodiment of the invention in which a defined volume of plastic melt is initially fed into a channel 585 and pot bore 640, prior to injection to cavity 9g through nozzle bore 20. As shown, a valve pin 580 is used to close off the flow connection from a main bore 620 into a distribution manifold 515, between the manifold channel 582 and bores 585/640/20 thus defining a predetermined defined volume of melt which can be controllably injected via an injection cylinder 565 which is controllably drivable via actuator 514 to shoot/inject the defined volume of melt material through the bore 20 into cavity 9g. The rate of flow of the melt being injected via cylinder 565 may be controlled via controlled operation of any one or more of a

rotary valve 512, valve pin 20 or via the drive of the cylinder 565 itself. Cylinder 565 is controllably drivable back and forth 519 within bore 640 via actuator 514 in a conventional manner to thus control the rate of injection of melt from bore 640 through bore 20.

In accordance with the invention, sensor 69 records a selected condition of the melt and sends signals to CPU which in turn may be programmed according to a predetermined algorithm to control the operation of any one or more of actuator 545 which controls operation of pin 41, actuator 516 which controls operation of rotary valve 512 or actuator 514 which controls operation of cylinder 565. As described above with regard to other embodiments sensor 69 may alternatively be located in other locations, e.g. cavity 9g or bores 640 or 585 depending on the melt properties (typically pressure) to be monitored/controlled and the molding operation(s) to be controlled. As shown in Fig. 31 and as described above, the algorithm of the CPU is simultaneously controlling the operation of the actuator 518 associated with another nozzle (not shown) via sensor signals sent by a sensor associated with the other nozzle.

Figure 32 shows a valve pin 700 having a smooth outer surfaced curvilinear bulbous protrusion 750 for controlling melt flow from manifold channel 760 to nozzle channel 710. The pin 700 is slidably mounted in nozzle channel 710 having a distal extension section 720 having a tip end 730 for closing off gate 740 when the pin is appropriately driven to the position shown in Fig. 34. The pin 700, 830 is controllably slidable along its axis Z. The bulbous protrusion 750 as shown in Figs. 32, 32A is in a flow shut-off position where the outer surface of a maximum diameter section 755 of the bulb makes engagement contact with a complementary shaped interior surface of the channel 765 sufficient to prevent melt flow 770 from passing through the throat section 766 where and when the bulb surface 755 engages the inner surface 765 of the flow channel. As perhaps best shown in Fig. 39, the bulb 750 has an intermediate maximum

diameter section which is intermediate an upstream smooth curvilinear surfaced portion 820 and a downstream smooth curvilinear surfaced portion 810. Melt flow 900 flowing under pressure from manifold or hotrunner channel 770 toward nozzle channel 710 passes through flow controlling passage 767. The melt flow is slower the narrower passage 767 is and faster the wider that passage 767 is. Passage 767 may be controllably made narrower or wider by controlled CPU operation of actuator 790 as described above with reference to other embodiments via an algorithm which receives sensor variable signals from a sensor such as sensor 780. In the Figs. 32-39 embodiments, the passage 767 is gradually made wider and flow increased by downstream movement of the bulb 750 toward the gate740. By contrast, in the Fig. 40 embodiment, the passage 767 is made narrower by downstream movement of the bulb 750 from the position shown in Fig. 40 toward the throat 766 restriction section, and made wider by upstream movement of the bulb 750 away from the gate 740.

As shown in Fig. 39, the maximum diameter section typically has a straight surface 755 forming a cylindrical surface on the exterior of the bulb 750 having a diameter X. The throat 766 has a complementary straight interior surface 765 in the form of a cylinder having the same diameter X as the surface 755. Thus as the bulb 750 is moved in an upstream direction (away from the gate), from the position shown in Fig. 39, the flow controlling restriction 767 gets narrower and the melt flow 900 is gradually slowed until the surface 755 comes into engagement with surface 765 at which point flow is stopped at the throat 766. The same sequence of operation events occurs with respect to all of the embodiments shown in Figs. 32-39. The maximum diameter surface 755 does not necessarily need to be cylindrical in shape. Surface 755 could be a finite circle which mates with a complementary diametrical circle on mating surface 765. The precise shape of surface 755 may be other than circular or round; such surface 755

could alternatively be square, triangular, rectangular, hexagonal or the like in cross-section and its mating surface 765 could be complementary in shape.

Figs. 34, 34A show a third position where the end of the extended pin closes off flow through gate 740. Figs. 32, 32A show a position where flow 900 is shutoff at throat 766. Figs. 33, 33A show a pin/bulb position where flow 900 is being controlled to flow at a preselected rate. Any one or more positions where the bulb surface 755 is further or closer to surface 765 may be controllably selected by the CPU according to the algorithm resident in the CPU, the flow rate varying according to the precise position of the bulb surface 755 relative to the mating surface 765.

Figs. 35, 36 show an embodiment where the pin does not have a distal end extension for closing off the gate 740 as the Figs. 32-34 embodiment may accomplish. In such an embodiment, the algorithm for controlling flow does not have a third position for closing the gate 740.

Figs. 37-38A and 40 show an embodiment where the longitudinal aperture 800 in which the pin 830 is slidably mounted in bushing or mount 810 has the same or a larger diameter than the maximum diameter surface 755 of bulb 750. The aperture 800 extends through the body or housing of heated manifold or hotrunner 820 and thus allows pin 830 to be completely removed by backwards or upstream withdrawal 832, Fig. 37A, out of the top end of actuator 790 for pin replacement purposes without the necessity of having to remove mount or bushing 810 in order to replace/remove pin 830 when a breakage of pin 830 may occur. The bushing or mount 810 is typically press fit into a complementary mounting aperture 850 provided in the body or housing of manifold or hotrunner 820 such that a fluid seal is formed between the outer surface of bushing or mount 810 and aperture 850. The central slide aperture for pin 830 extends the length

of the axis of actuator 790 such that pin 830 may be manually withdrawn from the top end of actuator 790.

As described above with reference to Figs. 1-31, the slidable back and forth movement of a pin 830 having a bulb 750, Figs. 32-40, is controllable via an algorithm residing in CPU or computer, Fig. 35 which receives one or more variable inputs from one or more sensors 780.

The melt flow 900 is readily controllable from upstream channel 770 to downstream 710 channel by virtue of the ready and smooth travel of the melt over first the upstream smooth curvilinear surface 820 past the maximum diameter surface 755 and then over the smooth downstream curvilinear surface 810. Such smooth surfaces provide better control over the rate at which flow is slowed by restricting passage 767 or speeded up by making passage 767 wider as pin 830 is controllably moved up and down. The inner surface 765 of throat section 766 is configured to allow maximum diameter surface 755 to fit within throat 766 upon back and forth movement of bulb 750 through throat 766.